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International Treaties and Active Experiments in Space

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Satellite explorations of the near earth environment have vastly increased our understanding of space plasmas and their interactions with systems. A logical next step involves active experiments in which small quantities of matter and energy are injected into space environments. These experiments seek to verify tentative, scientific understanding and to identify ways to control environmental effects on systems. Serious questions may be raised regarding the legitimacy of conducting active experiments in space under United States military auspices. Here we review the treaty obligations regarding space environment modification to which the United States government has committed itself. Experiments involving the detonation of nuclear devices or interference with foreign space assets, especially "national technical means of verification," are explicitly forbidden. In planning these experiments great care must be exerted so that they produce no "widespread, long-lasting or severe effects" on the environment. We also review active experiments programs conducted by U.S. civilian and foreign space agencies. Finally, the treaty restrictions are applied to the case of a hypothetical experiment to establish the

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feasibility of controlling the flux of energetic particles trapped in the earth's radiation belts. An ability to reduce trapped radiation would increase orbit selection options for future space-based surveillance systems. Keywords: cont'd (previous page)

Preface

The authors wish to thank Dr. Andrew Yau of the National Research Council of Canada and Prof. John Winckler of the University of Minnesota for the use of imagery from the Waterhole and ECHO 7 experiments.

Contents

Illustrations

International Treaties and Active Experiments in Space

1. INTRODUCTION

It is important to scrutinize the environment in which warfare is conducted, from the viewpoints of offense, defense and systems limitation. The potential role of environment on warfare has been long recognized. History records many defeats suffered by armies whose leaders failed to properly analyze and consider environmental effects.

Today's military is called upon to operate in a totally new theater, the high frontier of space. Thirty years into the space age we are still trying to understand and specify the space plasma environment and predict its effects on the operations of highly sophisticated military systems. Two years ago the Air Force Geophysics Laboratory (AFGL), initiated an active space experiments program as the next logical step in the chain of understanding, predicting, and controlling environmentally induced systems-limiting effects. Up to this time, space scientists have conducted primarily passive experiments which characterize the highly variable, naturally occurring phenomena. Working hypotheses are then devised consistent with the data and the known laws of physics. These hypothetical models are intrinsically predictive and demand verification through controlled experiments. Whereas passive experiments explore what nature provides, active experiments seek to test the hypotheses by eliciting predicted responses to controlled perturbations of existing space environments. The perturbing agents can be chemical, particle beam, or electromagnetic wave injections.

(Received for Publication 30 August 1989)

Within the United States, space research is carried out through a complex web of civilian and military agencies whose justification for funding can be quite different. A scientific proposal to the National Science Foundation (NSF) may be funded after peer review establishes that the research is "good" science. For Department of Defense (DoD) funding, potential military applications must also be identified. Herein lies a difficulty of perception. Active space experiments conducted by scientists supported by DoD involve modifications of the space environment that may appear to be contrary to international treaty commitments of the United States government.

In this report we first review the rationale for a military interest in space. We then present critical portions of texts related to space experimentation, excerpted from international treaties signed by the United States government. The next section synopsizes active experiment programs conducted under U.S. civilian and foreign space agency sponsorship. Attention is directed to the parallels between the efforts of U.S. and USSR space scientists. We then discuss the military implications of a hypothetical radiation belt control experiment. It seeks to mitigate the systems-limiting effects of natural radiation on the operation of microelectronic circuitry by actively reducing the trapped, energetic ion and electron populations of the radiation belts. We demonstrate that feasibility testing of this concept would violate neither the letter nor the spirit of existing U.S. space treaty obligations. The final section summarizes the conclusions of this report.

2. MILITARY PRESENCE IN SPACE

Before discussing the legal implications of "space environment modification" experiments it is useful to reflect on why there should be a military interest in active experiments in space. The United States military mission in space, as elsewhere, is to maintain peace or to prosecute warfare. As stated in President Carter's space directive of 20 June 1978.[1]

> The United States will pursue activities in space in support of its right of self-defense and thereby strengthen national security, the deterrence of attack and arms control agreements.

and

> The United States will develop and operate on a global basis active and passive remote sensing operations in support of national objectives.

These statements are related to each other in terms of the primary function of the U.S. military in space, namely Command, Control and Communications (C^3). These are essential elements for maintaining a stable peace or conducting modern warfare. Without reliable and timely information provided by remote sensing instrumentation on surveillance satellites, arms control agreements such as SALT or ABM would be virtually impossible. Threats to space-based C^3 assets can result from hostile activities of foreign agents or from the hazardous plasma and radiation environments in which they must operate. Threats of the first kind, overt hostile activities against our national space assets, must be regarded as extremely serious violations of international treaties, bordering on acts of war.

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1. Schichtle, C. (1983) *The National Space Program from the Fifties into the Eighties*, National Defense University Press, pp 107.

The specification, prediction and mitigation of systems-limiting environmental effects on the operations of space C^3 systems is a major concern of AFGL's Space Physics Division. The problem is approached on three levels: (1) Identify and quantify environmental threats to spacecraft due to major solar or geomagnetic disturbances, (2) Model and predict the "space weather" to be encountered by various AF/DoD systems, and (3) Mitigate environmentally induced, degrading effects on space system operations. Mitigation can be effected passively through hardening systems' component materials against specific hazards or through active control of the environmental medium. For example, differential spacecraft charging can be reduced by coating vehicle surfaces with thin layers of conducting paint or by adding a plasma beam emitter to actively clamp the spacecraft potential to that of the environment. For C^3 satellites that must operate in the earth's radiation belts or at geostationary altitude, single event upsets of on-board computers reduce system reliability and on-station time. The susceptibility of micro-processors and memory chips to such upsets can be reduced either through radiation hardened devices or by actively reducing the radiation trapped in specific magnetic field shells. A possible technique for reducing trapped radiation, suggested by a Soviet scientist,[2] is described in Section 4 of this report. Here we are more interested in the legal implications of active perturbation/control experiments rather than in specific techniques.

The military goal of active space experiments is to control selected portions of the space environment to enhance U.S. military operations. To proceed from concept to systems that alter portions of the space environment, many decision points must be passed. Are the ideas technically feasible? Are they quantitatively within reach or science fiction? What are the collateral effects on the space and atmospheric environments? Are they simply new manifestations of old weapons concepts already forbidden by prior international treaties and laws? If, at the system's level, the answer to the last question is "yes", to what degrees are feasibility analyses and testing allowed or justified?

3. INTERNATIONAL TREATY OBLIGATIONS AND RESTRICTIONS

The ongoing debate over the restriction range of the ABM treaty has focused attention on the fact that the United States has voluntarily accepted limitations to the military uses of space. These agreements were accepted and perceived as useful guidelines for controlling the expansion of the arms race into new areas. The actual number of accepted agreements is small. In the following paragraphs we list the most important texts in chronological order, as they apply to the conduct of active experiments in space.

The 1963 N .clear Weapons Tests Ban Treaty is the first document agreed to by the United States, the United Kingdom and the Soviet Union. Article 1 of this treaty states:[3]

> Each of the parties to this treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapons tests explosion, in any place under its jurisdiction or

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2. Trakhtengerts, V. Yu (1983) Alfven Masers, *in Active Experiments in Space*, ESA SP-195, pp. 67-74.
3. Dupuy, T.N. and Hammerman, G.M. (1973) *A Documentary History of Arms Control and Disarmamen* R.R. Bowker Co., NY, pp. 524-526.

control: in the atmosphere; beyond its limits including outer space; or underwater including territorial waters or high seas.

This was followed in 1967 by the United Nations sponsored "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies." This treaty establishes the principle that space belongs to no nation, and that its exploration and use are to be for the benefit of all mankind. Article 4 extends the restriction of the Nuclear Test Ban treaty to exclude all nuclear weapons from space.[1]

> States parties to the treaty undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any manner.

The same article also forbids the "establishment of military bases ...the testing of any type of weapon and the conduct of military maneuvers on celestial bodies." It does however, recognize a legitimate military function in space:

> The use of military personnel for scientific research or for any other peaceful purpose shall not be forbidden.

For the United States government the word "peaceful" means "non-aggressive".[4]

Further guidelines on the conduct of experiments in space and on the Moon are outlined in Article 9 which requires parties to the treaty to:[1]

> ...conduct exploration ... so as to avoid their (space and celestial bodies) harmful contamination and also adverse changes in the environment of Earth ...

If there is any reason to believe that any activity or experiment planned by a state or its nationals could cause adverse effects on the space activities of another state they must:

> ...undertake appropriate international consultation before proceeding with any activity or experiment.

In 1972 the United Nations established a "Convention on International Liability for Damage Caused by Space Objects,"[5] signed and ratified by both the US and the USSR. It recognizes the duty to pay compensation for damage done as a result of space objects impacting the surface of the earth and aircraft (Article 2) and the space objects of other nations (Article 3). On the basis of this treaty, the USSR paid damages to Canada following the reentry of the nuclear powered COSMOS 954 satellite in January 1978.

In May 1972 President Nixon and General Secretary Brezhnev signed the Anti-Ballistic Missile (ABM) treaty. While the ABM aspects of the treaty are beyond the scope of this essay, the statements regarding treaty compliance are germane. Article 12 states:[6]

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4. Reijnen, G.C.M. (1981) *Utilization of Outer Space and International Law*, Elsevier, Amsterdam, pp. 45.
5. Forbosch, M.D. (1982) *Outer Space and Legal Liability*, Martinus Nijhoff Publishers, The Hague, pp. 232-243.
6. Carter, A.B. and Schwartz, D.N., ed. (1984) *Ballistic Missile Defense*, Brookings Institute, Washington, DC, p. 430.

(1) For the purpose of providing assurance of compliance with the provisions of this treaty, each party shall use national technical means of verification at its disposal in a manner consistent with generally recognized international law.

(2) Each party undertakes not to interfere with the national technical means of verification of the other party.

Positive interference with the "national technical means of verification" could undermine the geopolitical stability of the post World War II era.

Following the United Nations Conference on the Human Environment held in Stockholm in 1972, the United States government undertook a serious review of principles applying to environmental modification. The Convention on the Prohibition of Military or any Other Hostile Use of Environmental Modification Techniques[7] was ratified by the United States Senate and signed into law by President Carter in 1979. The clear intent of this treaty is to set agreed limits to use of environmental modification techniques in the conduct of warfare. Nonetheless, its proscription in Article 1 of techniques that have "widespread, long-lasting and severe effects" provide a prudent guideline in the planning and conduct of scientific experiments that involve environment modification.

The intent of the various treaties is not to prohibit the scientific exploration and use of space by the military. Rather they provide prudent guidelines to ensure a stable peace and to preserve the integrity of the space environment. Only the introduction or explosion of nuclear devices into space is explicitly banned. In planning active experiments in space, care must be taken to avoid: (1) widespread, long lasting, or severe contamination of the Earth's space environment, and (2) interference with the operation of foreign or domestic space assets. The prohibition against nuclear devices in space is not an issue for active experiments described in this report. Collateral damage from active space experiments to other spacecraft can be avoided by careful mission planning in cooperation with NASA and/or NORAD. Clearly, active space experiments may be conducted by any nation as long as they adhere to the restrictions cited above.

4. OTHER ACTIVE EXPERIMENT PROGRAMS

During the past decade, active experiments in space have played a growing role in national and international space science. This section contains a brief synopsis of these active experiments as they pertain to our present study.

Within the United States, NASA and the Department of Energy's Los Alamos National Laboratory (LANL) have sponsored a large number of chemical release experiments aimed at understanding the electric fields that drive plasma transport at high magnetic latitudes. A number of chemical releases are planned by NASA subsequent to the launch of the joint NASA/DoD Combined Release Radiation Effects Satellite (CRRES) at both high and low altitudes . The low altitude releases will be used to trace neutral winds, to generate holes in the ionosphere and to induce a form of plasma

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7. Osmanczyk, E.J. (1985) *The Encyclopedia of the United Nations and International Agreements*, Taylor and Francis, Philadelphia, pp. 517-518.

turbulence whose natural analog, equatorial spread F, interferes with radio communications. At high altitudes, chemical releases will be used to understand how: (1) weak magnetic fields bring massive ionization to rest and (2) trapped energetic electrons in the radiation belts can be destabilized by actively changing the dielectric properties of the medium.

One of the most interesting chemical release experiments, Project Waterhole, was sponsored by the National Research Council of Canada and LANL.[8] A sounding rocket carried 88 kg of highly explosive nitro-methane and ammonium nitrate to an altitude of 300 km in close proximity to a stable auroral arc. On detonation, water, nitrogen and carbon dioxide molecules ionized by exchanging an electron with ambient oxygen ions. The positively charged molecular ions then absorbed environmental free electrons. The net result was that the ionosphere lost ion-electron pairs. When the process is repeated many times, the total number of ion-electron pairs decreases significantly, creating a "hole" in the ionospheric plasma density.

As shown in the all-sky pictures of Figure 1 the stable auroral arc dimmed noticeably after the detonation (0338) and then recovered in brightness (0345). The chemical release depleted the local ionosphere of the charged particle carriers required to support the auroral arc's current system. Since an auroral arc is a visible manifestation of coupling between the ionosphere and an electrical generator many thousands kilometers removed in the distant magnetosphere, the effects of Waterhole were certainly widespread. They were however, neither long-lasting nor severe.

NASA has also been sponsoring a series of chemical releases designed to understand conditions required to induce critical ionization phenomena. These experiments test the hypothesis proposed by Nobel laureate Hannes Alven, that chemically neutral matter streaming across magnetic field lines at velocities greater than the ionization potential equivalent velocity can undergo catastrophic ionization if a few seed ion-electron pairs are present in the cloud. The results of these experiments are of interest for astrophysicists to understand the origin of planetary systems and for engineers to explain Shuttle glow phenomena.

When NASA was embarking on its program of chemical releases in space in the early 1970's, it commissioned a blue-ribbon panel to investigate their possible environmental effects. The panel studied and examined every conceivable effect, from that on the local atmosphere and other space vehicles to the viewing capabilities of optical astronomers. Using arguments similar to those outlined in the last section, the panel came to a unanimous conclusion.[9]

> No deleterious environmental effects - of a widespread or long-lasting nature - are anticipated from chemical releases in the upper atmosphere on the scale and type indicated for the CRM program.

The acronym CRM stands for Chemical Release Module, the NASA designation before it became CRRES. The mission planners must introduce perturbations large enough to produce measurable

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8. Yau, A.W., Whalen, B.A., Creutzberg, F., Pongratz, M.B., and Smith, G. (1981) Observations of particle precipitation, electric field and optical morphology of an artificially perturbed auroral arc: Project Waterhole, *J. Geophys. Res.* **86**:5601-5613.

9. Heppner, J.P. and Dubin, M. (1980) *Environmental Analysis of the Chemical Release Module Program*, NASA Technical Paper 1750.

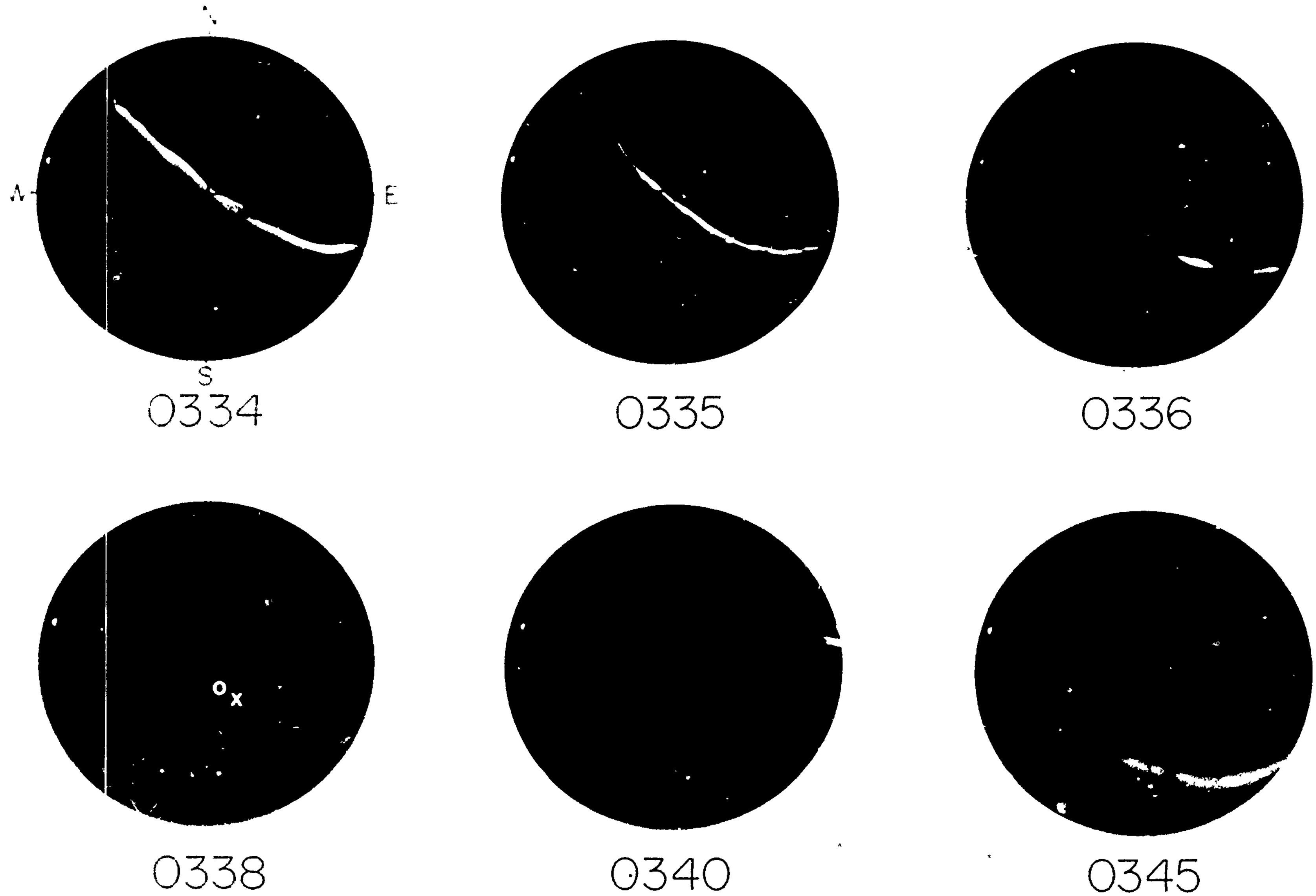

Figure 1. All-Sky Images Taken at Ft. Churchill Rocket Range at Time of Waterhole Launch. The X,0 marks on the image at 0338 give the location of chemical injections relative to a bright auroral arc.

effects, but small enough to dissipate quickly. The point of active experiments is to understand the environment, not to overwhelm it.

In conjunction with the University of Minnesota, NASA has also conducted a number of high-energy electron beam experiments known as ECHO.[10] The Primary objective is to understand the long range propagation of electron beams in the earth's magnetic field (Figure 2). The electron bursts emitted from rockets in the northern ionosphere are measured after reflection from magnetic mirrors in the southern hemisphere. In February 1988 the NASA and AFGL launched the ECHO-7 rocket from the Poker Flats range in Alaska. Of particular interest to Air Force scientists are the causes for about 90 percent of the electrons becoming trapped in the magnetosphere due to wave-particle interactions. Figure 3 shows the first pictures of an electron beam propagating from the ECHO-7 main payload. The image came from a TV camera located on a free-flying subpayload about 0.5 km above the emitter.

The National Science Foundation (NSF) support for active experiments has largely concentrated in the area of wave injections from the ground. Facilities at Arecibo in Puerto Rico and Fairbanks, Alaska are used to heat the local ionosphere with the goal of understanding non-linear plasma phenomena such as wave mode coupling, parametric instabilities, ponderomotive forces, the self-focusing of waves, and electron acceleration processes.[11] Although the emission of megawatts of RF power from ground-based antennas seems quite ominous, the power flux is generally about a milliwatt per square meter at ionospheric altitudes. Within a few seconds of antenna turnoff the ionosphere relaxes to a quiet state.

NSF has also supported a VLF transmitting station at Siple, Antarctica, operated by Stanford University.[12] Waves emitted from this station pass with severe diminution through the ionosphere, where they are ducted along magnetic field lines. Near the magnetospheric equator the waves interact with energetic, trapped electrons, causing them to pitch-angle scatter into the atmospheric loss cone. Within a bounce period of approximately one second the electrons impact the upper atmosphere where they are lost. These experiments provide information on long distance propagation of low frequency waves and wave-particle interactions in space. They also lay the technological foundations for controlling the energetic electron contents of the radiation belts. However, the actual active experiments last but a few minutes and their effects on the ionosphere also vanish within seconds of transmitter turnoff.

International cooperation has been an important aspect of active experiments in space. This cooperation reflects both common interests and the need to share expertise and costs. A large number of experiments have been conducted through cooperative efforts between U.S., Canadian, Japanese, and west European scientists. The most important of these was the Active Magnetosphere Particle Tracer Explorer (AMPTE) in which three satellites sponsored by the U.S., the United Kingdom and the

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10. Winckler, J.R. (1980) The application of artificial electron beams to magnetospheric research, *Rev. Geophys. and Space Sci.* **18**:659-682.
11. Gordon, W.E., Showen, R., and Carlson, H.C. (1971) Ionospheric heating at Arecibo; first tests, *J. Geophys. Res.* **76**:7808.
12. Helliwell, R.A. and Katsufrakis, J.P. (1974) VLF wave injection into the magnetosphere from Siple Station, Antartica, *J. Geophys. Res.* **79**:2511.

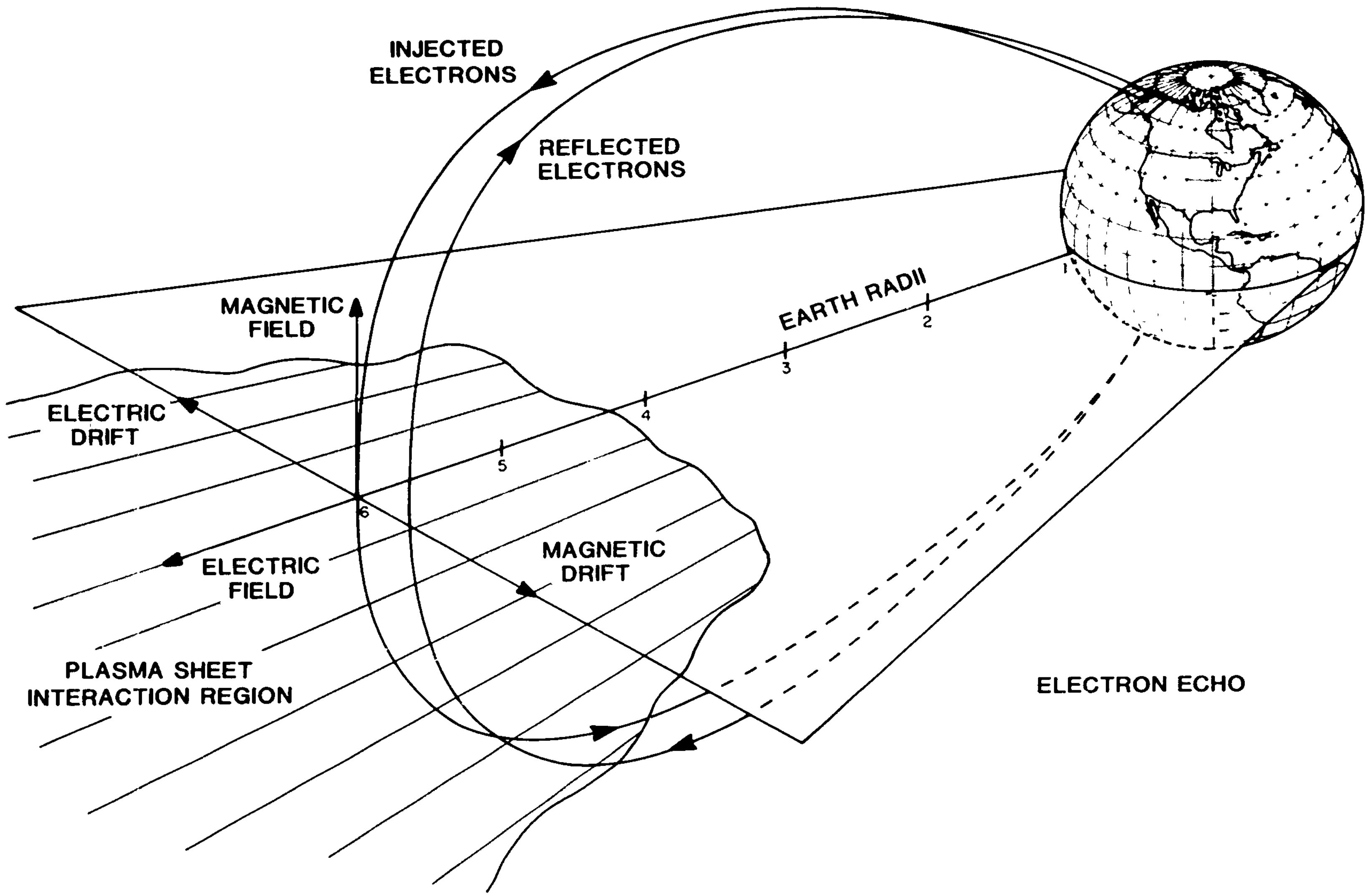

Figure 2. Concept for ECHO Experiments in Which Electrons Emitted From a Rocket in the Northern Hemisphere, Travel Along the Earth's Magnetic Field to the Southern Ionosphere, Where They Mirror Back to Their Source

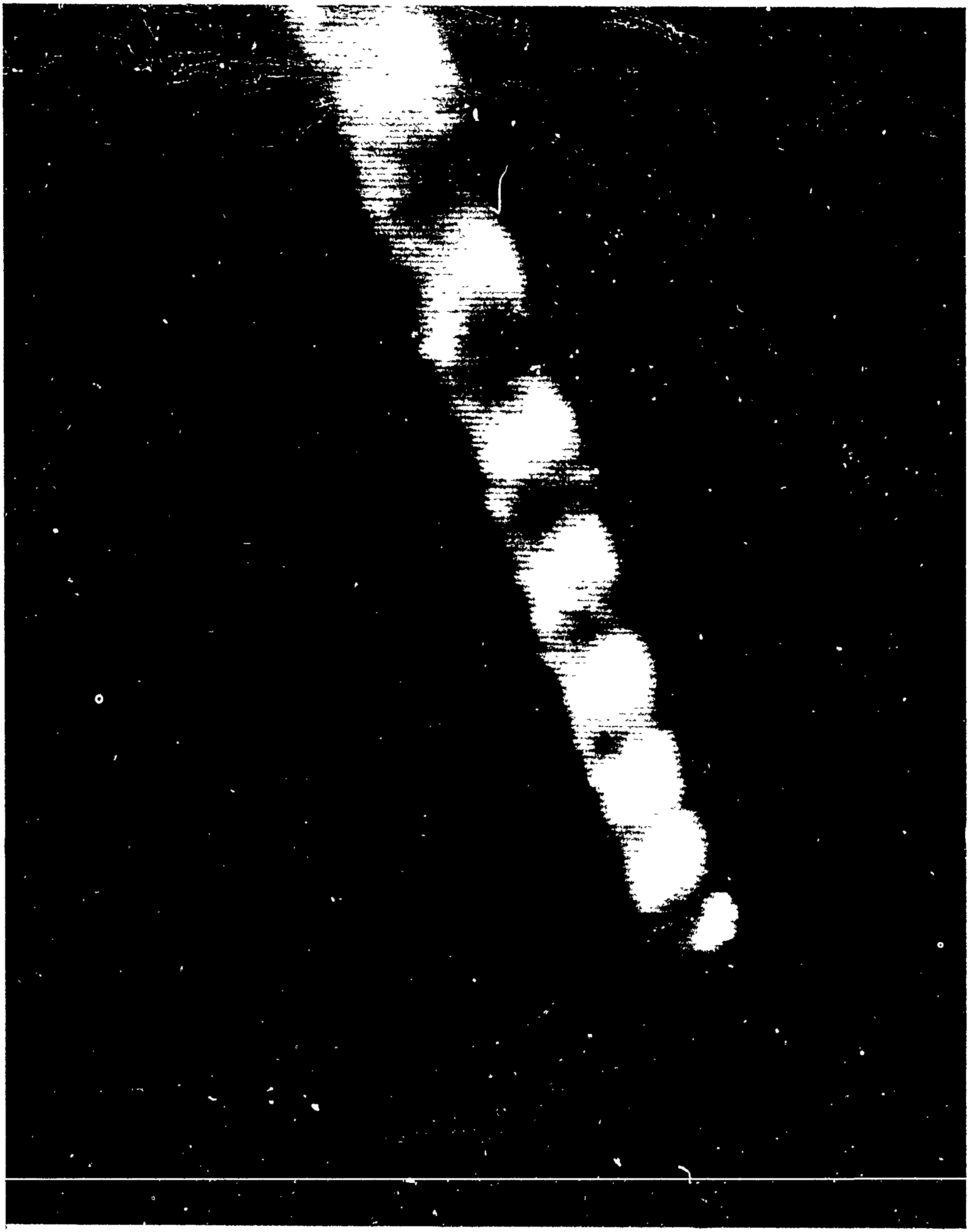

Figure 3. TV Image of Electron Beam Spiralling Along Earth's Magnetic Field Lines During the ECHO-7 Rocket Flight. The bright spot at lower right side comes from the accelerator section of ECHO.

German Federal Republic were launched into complementary orbits in interplanetary space.[13] Chemical releases from the German satellite were used to understand ion acceleration and transport in the solar wind, the dynamics of artificial comets and the energization of particles in the earth's magnetotail.[14]

A view of the scientific interests of the Soviet space program is provided through their international cooperative efforts. By and large the U.S. and the USSR efforts seem to follow parallel lines. The objectives and instrumentation of the French-USSR ARAKS[15] (Artificial Radiation and Aurora between Kerguelen and the Soviet Union) rockets are very close to that of the ECHO series. Where the U.S. effort emphasized particle transmission, the ARAKS team stressed the generation of VLF radiation.[16] Radiation and beam transmission are complementary to one another. The ARAKS study also considered the effects of very low frequency radiation in the equatorial magnetosphere. This is similar in objective to the Stanford/Siple effort in the U.S. mentioned above; only the source of the VLF is different.

In 1987 the Soviet Academy of Science announced a series of space missions planned for launch in the late 80s to early 90s period. There are two active experiment missions listed in these plans called APEX and ACTIVE-IR. As shown in Figure 4 both missions consist of a main satellite primarily responsible for active perturbations and a diagnostic subsatellite flying in a trailing orbit.[17] APEX is a follow-on to ARAKS, in which both electron and xenon ion beams will be used as active probes to stimulate artificial auroras, to modulate magnetosphere/ionosphere coupling, and to excite nonlinear structures within the perturbed plasmas.

The main function of ACTIVE-IR will be to inject whistler or VLF frequency radiation into the magnetosphere. This will be accomplished using a 20 m loop antenna, emitting 5 kW of radiation at a frequency of 9.6 + 0.2 kHz. Radiation in this frequency band should efficiently destabilize energetic electrons trapped in the radiation belts. This experiment is very similar in objective to that being conducted at the Siple station in Antarctica. The Soviets have the advantage of injecting the VLF radiation directly into deep space without losing power as the wave fields propagate across the ionosphere.

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13. The AMPTE mission has been the subject of a number of special issues of prestigious scientific journals. See *IEEE Transactions of Geoscience and Remote Sensing*. **GE-23**, 1985; *Geophysical Research Letters* **12**:303-332, 1985; *Nature* **320**:700-723, 1986.

14. Bernhardt, P.A., Roussel-Dupre, R.A., Pongratz, M.B., Haerendel, G., Valenzuela, A., Gurnett, D.A., and Anderson, R.R. (1987) Observations and theory of the AMPTE magnetotail releases, *J. Geophys. Res.* **92**:5777-5794.

15. Lavergnat, J. (1981) *The French-Soviet Experiments on ARAKS: Main Results, in Artificial Particle Beams in Space Plasma Studies*, ed. by B. Grandal, Plenum Press, NY, pp 87-100.

16. Gringauz, K.I., Shutte, N.M., Izhovkina, N.I. and Pulinets, S.A. (1983) On the Stimulated Precipitation of Electrons and the Mechanism of Wave Generation in the Whistler Range in the "ARAKS" Experiment, *Active Experiments in Space*, ESA SP-195, pp. 137-140.

17. Triska, P., Jiricek, F., Velicky, V. and Vojta, J. (1988) A Subsatellite for Mother-Daughter Active Space Experiments, Twenty-Seventh Pleanry Meeting of COSPAR, 18-29 July 1988, Helsinki, Finland, p. 346.

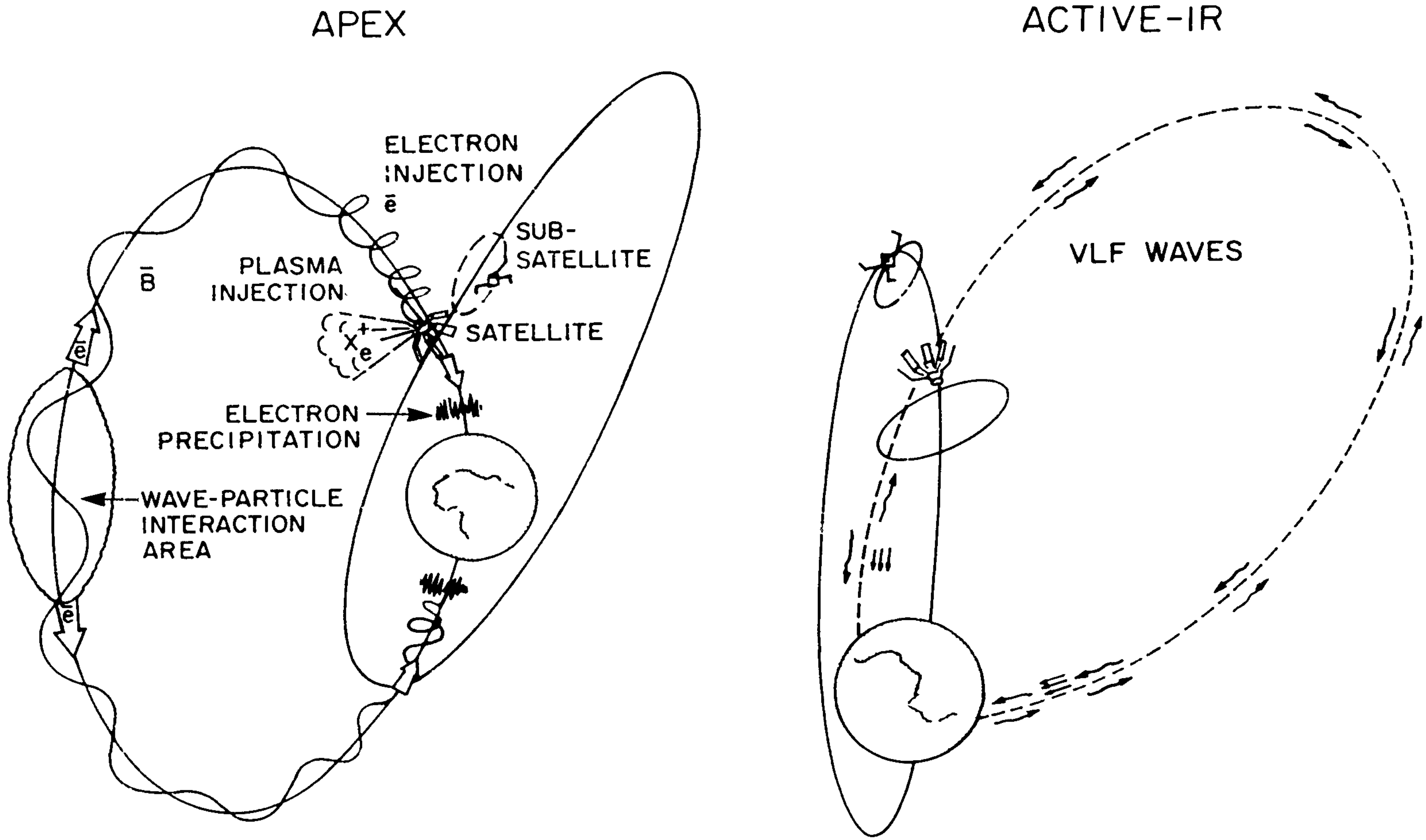

Figure 4. Schematic Representation of the Soviet Active Experiments Satellites APEX and ACTIVE-IR Scheduled for Launch in 1988-1989

Just as in the U.S., the USSR has shown a continuing interest in the effects of ground-based radiation on space plasmas.[18] At the "Active Experiments in Space Symposium," in 1983 sponsored by the European Space Agency, Soviet scientists presented an experimental paper on the acceleration of electrons by radiation from ground and rocket-based RF transmitters. At the same symposium V. Yu Trakhtengerts[2] presented a theoretical analysis for an ionospheric heater experiment that could be used to launch Alfven waves into the magnetosphere. Near the equatorial plane these waves could cause energetic ions to pitch angle scatter into the ionospheric loss cone. From the viewpoint of technology transfer, the Soviets have told us how to modify the radiation belts in a way that could be of great potential benefit to future U.S. space surveillance missions.

5. ACTIVE SPACE EXPERIMENTATION:

In this section we explore the legal implications of conducting active space experiments either for validating space plasma theories or for testing environment perturbation concepts. The key word is "testing." The objective of active space experiments is to understand the physics of perturbing an environment in terms of the quality and quantity of energy delivered over some time scale. For concreteness we consider a specific experiment in which intense emissions from ground based antennas perturb the near earth space plasma. The elements required for the experiment are outlined in Figure 5. Large electrical generators power high-gain, radio frequency (RF) antennas that transmit electromagnetic radiation to desired locations in the ionosphere. Depending on the wave characteristics, the ionospheric plasma would produce a number of interesting responses with potential military applications. Do such experiments, when conducted by U.S. military scientists, contradict the letter or spirit of our treaty obligations?

It has long been known that large scale electrical currents, driven by solar radiation and/or geomagnetic effects, flow in the earth's ionosphere. Ohm's law tells us that the intensity of the currents are proportional to the ionospheric electric fields and conductivities. A number of experiments conducted by U.S. and USSR scientists show that existing antennas, radiating in the 5 to 10 MHz frequency range can be used to modulate the temperature of electrons in the earth's ionosphere. This in turn modulates the electrical conductivity of the heated region. Because electron temperatures relax very quickly once the radiation is turned off, it is possible to modulate the ionosphere currents at frequencies from less than 1Hz to more than 10 kHz. The ionosphere could thus be used as a large virtual antenna. We wish to consider an application other than for VLF/ULF communications.

Magnetic field lines that thread the ionosphere at mid to low latitudes trap very energetic electrons and ions in a region known as the Van Allen or radiation belts. Theory tells us that once caught in a static magnetic field, energetic particles should stay trapped in the radiation belts forever. This however, does not happen. The earliest space missions found that the radiation belts are very dynamic. The radiation intensity rises during magnetic storms and declines in the following weeks.

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18. Koorazhkin, R.A., Mogilevsky, M.M., Moltchanov, O.A., Galperin, Yu. I., Djordijio, N.D., Lissakov, Yu. V., Bosqued, J.M., and Reme, H. (1984) Interaction between neutral hydrogen and solar wind: spacecraft measurements of H+ on the earth's orbit, *Geophys. Res. Lett.* **11**:705-708.

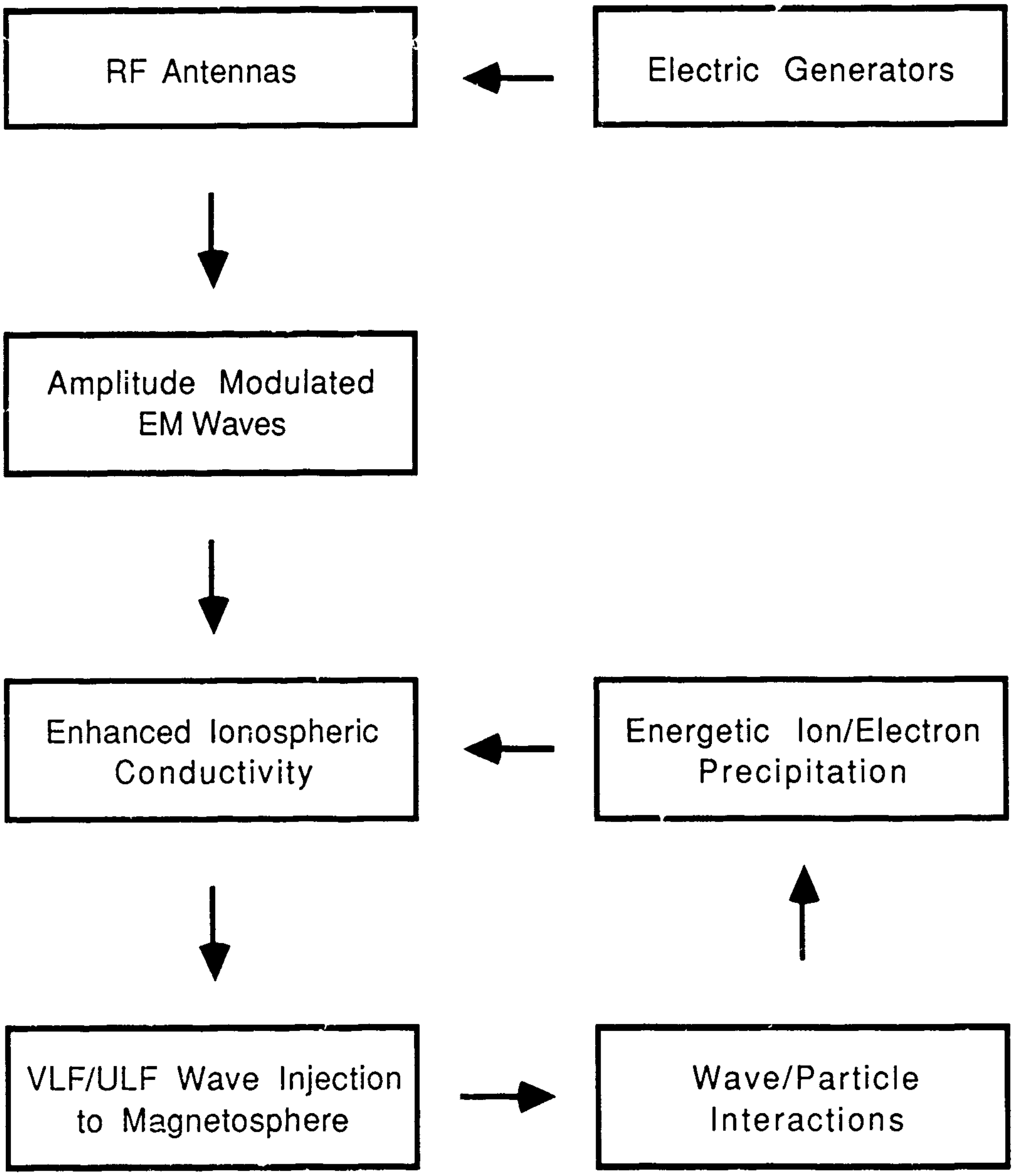

Figure 5. Flow Chart of Active Experiment to Clear Large Sections of the Radiation Belts for Greater Reliability for Advanced Surveillance Satellites

Processes generically known as pitch angle scattering cause energetic electrons to slowly change their orbits until they intersect the denser portions of the upper atmosphere where they collide with neutrals and are lost. A major success story of the late 1960's was the development of a theory that explained the main features of the pitch angle scattering of electrons from the radiation belts.[19, 20]

The main idea is that electrons moving in trapped orbits encounter VLF waves moving in the opposite direction along the same magnetic field lines. The VLF waves originate with lightning discharges in the atmosphere and radiation from electrical grids on the surface of the earth. If the electrons see waves having the same frequency as their gyrofrequency around the magnetic field they are in resonance with each other. Not surprisingly, the waves either give up energy to or gain energy from the electrons. In encounters where the wave intensity grows, electrons scatter toward the atmosphere. Although this process adequately describes electron dynamics it does not apply to energetic ions.

For theorists this was a surprising result. Surely there must be ultra low frequency (ULF) waves in the radiation belt that resonate with the energetic ions. It would be useful to know how theory has failed or nature might be helped to pitch-angle scatter ions out of the radiation belts. The Soviet physicist Trahktengerts[2] suggested that the ionosphere was the problem. Instead of reflecting ULF waves back into space where they could grow in amplitude through resonant interactions, the ionosphere allowed them to be transmitted and lost. This situation could be changed by actively controlling the electrical conductivity of the ionosphere. In Trahktengert's view an actively modulated ionosphere could serve a dual purpose as an antenna to inject the desired ULF waves and a reflector to keep them in the desired flux tube in the radiation belts. Since energetic ions rapidly gradient-curvature drift around the earth, it is possible for a single, high-power antenna on the ground to empty a magnetic shell that circumscribes the entire globe.

Clearly, active experiments that provide information on the propagation, reflection, and amplification of ULF waves in space as well as the pitch angle scattering of energetic ions out of magnetic containment are of great scientific interest. But why might the U.S. and/or USSR military care? The answer lies in the growing need for reliable space-based surveillance by both sides as a "national technical means of verification" of arms reduction and control treaties. Future syst such as space-based radar flying between 6,000 and 12,000 km above the surface of the earth advantageously compromise between resolution and coverage when compared with systems in geostationary and low-earth orbit.[21] The major disadvantage comes from the inherent, comput intensive nature of the systems. Energetic particles in the radiation belts are expected to seriously degrade the performance of onboard, high density micro-processor and memory chips. The development of technologies that increase orbit selection for reliable space-based computer elements is thus, of fundamental military significance.

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19. Kennel, C.F. and Petschek, H.E. (1966) Limit of stably trapped particle fluxes, *J. Geophys. Res.* **71**:1.

20. Lyons, L.R. and Thorne, R.M. (1973) Equilibrium structure of radiation belt electrons, *J. Geophys. Res.* **78**:2142.

21. Tsandoulas, G.N. (1987) Space-based radar, *Science* **237**:257-262.

This is an example of environmental modification that in its applied or system stage would be long lasting, widespread, but benign. It is a manipulation of natural processes that would be of benefit to all mankind, in that the effectiveness of "national technical means of verification" and thus of arms control agreements, would be enhanced. To develop such a system for radiation belt control could result from international cooperation.

There is still one important legal hurdle to be overcome. Is it possible for the U.S., within the constraints of existing agreements, to conduct unilateral experiments to establish the technical feasibility of radiation belt depletion? Do the contemplated active experiments produce widespread, long lasting or severe contamination of the environment? Do they interfere with the operations of space assets of the U.S. or any foreign government?

As we have seen from experiments conducted by the civilian sector, within seconds of turn-off, the heating effects of ground antennas disappears in the ionosphere.[22] In this case, the reflectivity of the ionosphere for low frequency waves would also vanish. Thus, the wave activity required to maintain pitch angle scattering of energetic protons would fall to its low, natural levels. Ionospheric heating due to proton precipitation would also disappear within a few seconds due to natural atmospheric quenching. Thus, no long lasting or severe contamination of the ionosphere would occur during experiments to demonstrate feasibility.

In the actual conduct of radiation belt depletion experiments, an RF heater with the appropriate drive power and frequency for modulating ionospheric conductivity would have to be positioned at a mid-latitude site. Both the enhanced low-frequency wave activity and pitch angle scattering of protons can be verified using existing instrumentation already planned for the NASA/Air Force Combined Release Radiation Effects Satellite (CRRES) scheduled for launch in 1990. No danger would be posed to other satellites operating in the radiation belts by lower proton flux levels.

6. SUMMARY AND CONCLUSIONS

In this report we have considered the treaty obligations to which the United States has committed itself which relate to the performance of active experiments in space. These are considered in the context of research conducted and supported by scientists in Department of Defense laboratories where defined military objectives must accompany good science requirements. One important military objective for supporting active experiments is space environmental control.

Our review of the various treaties shows that there are three restrictions:

(1) Nuclear weapons are neither to be placed nor exploded in space.

(2) National technical means of verification are not to be interfered with.

(3) No widespread, long lasting, or severe contamination of space should result from the experiments.

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22. Imhof, W.L., Reagan, F.B., Voss, H.D., Gaines, E.E., Datlowe, D.W., Mobilia, J., Helliwell, R.A., Inan, U.S., and Katsufrakis, J. (1983) Direct observations of radiation belt electrons precipitated by the controlled injection of VLF, *Geophys. Res. Lett.* **10**:361-364.

From the current debate between the U.S. and the USSR over SDIO research it is clear that both sides recognize the legitimacy of analytical and laboratory studies required to establish physical principles and technical feasibility. Indeed, the defense related R&D efforts of all countries have a prime goal of establishing the technical options available to the nation's and potential adversary's leadership. In the case at hand, laboratory and paper exercises would quickly run their course demanding feasibility demonstrations in realistic natural environments. It appears that the construction of ground-based test facilities for conducting electron heating experiments in the ionosphere is also allowed under the restrictions stated above. The chief legal issues at this level would be concerned with environmental contamination and interference with the space assets of other nations. Through prudent experiment planning it should be possible to introduce enough energy into the ionosphere for short periods of time to establish the efficiency of induced pitch angle scattering in natural environments. This can be done without severe or long lasting effects on either the ionosphere or the magnetosphere. Within a few weeks of a magnetic storm, energetic electrons are cleared from the radiation belts by natural pitch angle scattering processes. Experiments conducted under U.S. Navy auspices show that energetic electrons and ions from the radiation belts can only penetrate to about 80 to 90 kilometers altitude, thus producing no effects on either the earth's surface or the ozone layer. Predictive-avoidance analyses would restrict experiment "on times" to periods when no low altitude satellite is in view.

Decisions regarding the development, testing and deployment of specific systems must include military and political considerations as well as technical feasibility. It is clear however, that even a limited ability to control space radiation effects could have strategic advantage of profound significance.

References

1. Schichtle, C. (1983) *The National Space Program from the Fifties into the Eighties*, National Defense University Press, p. 107.
2. Trakhtengerts, V. Yu (1983) Alfven Masers, *in Active Experiments in Space*, ESA SP-195, pp. 67-74.
3. Dupuy, T.N. and Hammerman, G.M. (1973) *A Documentary History of Arms Control and Disarmament*, R.R. Bowker Co., NY, pp. 524-526.
4. Reijnen, G.C.M. (1981) *Utilization of Outer Space and International Law*, Elsevier, Amsterdam, pp. 45.
5. Forbosch, M.D. (1982) *Outer Space and Legal Liability*, Martinus Nijhoff Publishers, The Hague, pp. 232-243.
6. Carter, A.B. and Schwartz, D.N., ed. (1984) *Ballistic Missile Defense*, Brookings Institute, Washington, DC, p. 430.
7. Osmanczyk, E.J. (1985) *The Encyclopedia of the United Nations and International Agreements*, Taylor and Francis, Philadelphia, pp. 517-518.
8. Yau, A.W., Whalen, B.A., Creutzberg, F., Pongratz, M.B., and Smith, G. (1981) Observations of particle precipitation, electric field and optical morphology of an artificially perturbed auroral arc: Project Waterhole, *J. Geophys. Res.* **86**:5601-5613.
9. Heppner, J.P. and Dubin, M. (1980) *Environmental Analysis of the Chemical Release Module Program*, NASA Technical Paper 1750.
10. Winckler, J.R. (1980) The application of artificial electron beams to magnetospheric research, *Rev. Geophys. and Space Sci.* **18**:659-682.
11. Gordon, W.E., Showen, R., and Carlson, H.C. (1971) Ionospheric heating at Arecibo; first tests, *J. Geophys. Res.* **76**:7808.
12. Helliwell, R.A. and Katsufrakis, J.P. (1974) VLF wave injection into the magnetosphere from Siple Station, Antartica, *J. Geophys. Res.* **79**:2511.
13. The AMPTE mission has been the subject of a number of special issues of prestigious scientific journals. See *IEEE Transactions of Geoscience and Remote Sensing*, **GE-23**, 1985; *Geophysical Research Letters* **12**:303-332, 1985; *Nature* **320**:700-723, 1986.

14. Bernhardt, P.A., Roussel-Dupre, R.A., Pongratz, M.B., Haerendel, G., Valenzuela, A., Gurnett, D.A., and Anderson, R.R. (1987) Observations and theory of the AMPTE magnetotail releases, *J. Geophys. Res.* **92**:5777-5794.

15. Lavergnat, J. (1981) *The French-Soviet Experiments on ARAKS: Main Results, in Artificial Particle Beams in Space Plasma Studies*, ed. by B. Grandal, Plenum Press, NY, pp 87-100.

16. Gringauz, K.I., Shutte, N.M., Izhovkina, N.I. and Pulinets, S.A. (1983) On the Stimulated Precipitation of Electrons and the Mechanism of Wave Generation in the Whistler Range in the "ARAKS" Experiment, *Active Experiments in Space*, ESA SP-195, pp. 137-140.

17. Triska, P., Jiricek, F., Velicky, V. and Vojta, J. (1988) A Subsatellite for Mother-Daughter Active Space Experiments, Twenty-Seventh Pleanry Meeting of COSPAR, 18-29 July 1988, Helsinki, Finland, p. 346.

18. Koorazhkin, R.A., Mogilevsky, M.M., Moltchanov, O.A., Galperin, Yu. I., Djordijio, N.D., Lissakov, Yu. V., Bosqued, J.M., and Reme, H. (1984) Interaction between neutral hydrogen and solar wind: spacecraft measurements of H+ on the earth's orbit, *Geophys. Res. Lett.* **11**:705-708.

19. Kennel, C.F. and Petschek, H.E. (1966) Limit of stably trapped particle fluxes, *J. Geophys. Res.* **71**:1.

20. Lyons, L.R. and Thorne, R.M. (1973) Equilibrium structure of radiation belt electrons, *J. Geophys. Res.* **78**:2142.

21. Tsandoulas, G.N. (1987) Space-based radar, *Science* **237**:257-262.

22. Imhof, W.L., Reagan, F.B., Voss, H.D., Gaines, E.E., Datlowe, D.W., Mobilia, J., Helliwell, R.A., Inan, U.S., and Katsufrakis, J. (1983) Direct observations of radiation belt electrons precipitated by the controlled injection of VLF, *Geophys. Res. Lett.* **10**:361-364.